Wet Antennas

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Introduction

During the development of the Amos antenna, I spent some time researching the behavior of different antennas when they become wet under rainy weather conditions.

I wanted to see what type of weather protection is enough for Amos antenna and I made some comparisons of different 2.4 GHz antennas under wet weather conditions and how water on antenna active and passive elements influence on the antenna characteristics.

The simulation program which I used was 4NEC2 and it has possibility to analyze antenna built from insulated wires [1] and calculate influence of wire insulations to overall characteristics of antenna using LD7 card. [2]

This insulation produces shortening effects in the wires, thus lowering the velocity factor.

Internally in the program the LD7 card is converted to an LD2 card using the below equation [1]:

L = 2e-7 * (Er * R/r) ^ (1/12) * (1 - 1/Er) * ln(R/r)

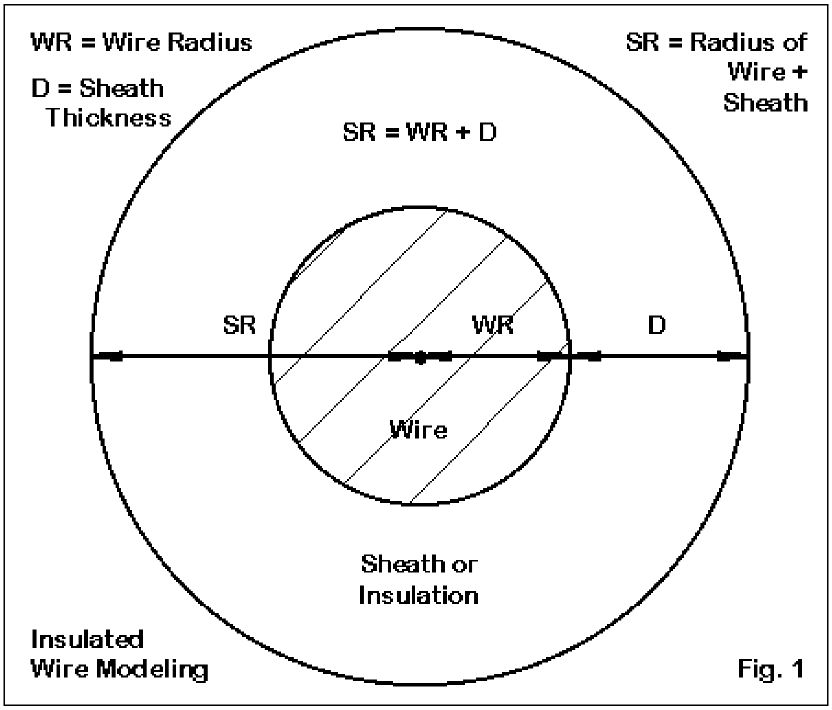
L	Value for distributed inductance in Henry/meter
Er	Dielectric constant (as specified in the LD7 card)
ln	Natural Logarithm
R	Radius of wire plus insulation (as specified in the LD7 card)
r	Radius of (bare) wire (as specified in the corresponding GW card)

This gives me the idea to simulate a moistened antenna as antenna built from insulated wires, where insulation is made of water!

The main problem for water and ice as isolator is its exceptionally high relative dielectric permittivity. For distillated water relative dielectric permittivity is in range of Er=34-78.

When we know that the relative dielectric permittivity for usual insulating materials made from plastic polymers that are used in electro technique (PE, PTFE, PVC, etc) is around Er= 2-4, then it is clear that moisten antenna is not the same as antenna made of PVC insulated wires.

It is not the same because of influence of very high relative dielectric permittivity of water to de-tuning of antenna resonant elements is the main problem which can directly lead to disastrous behavior of wet antenna.



Insulated Wire Modeling

Favorites and outsiders

It is expected that antennas with lower Q factors that is with higher radiation resistances will be less susceptible to elements de-tuning than antennas with lower radiation resistance and high Q factor.

Wide working SWR and gain bandwidth in which the antenna achieves expected performances is an important factor. Apart from the possibility of working on a larger frequency band, such antenna usually has higher efficiency and it is less sensitive to environmental conditions and surrounding objects influence.

On the other hand, antennas with narrow working SWR and gain bandwidth are usually much more susceptible to surrounding objects and environmental influences and they manifest this with rapid change of their properties, above all by change of their input impedance and directivity.

Yet according to that, it was possible to distinguish favorites and outsiders, but it was more exciting to investigate how all this phenomena is really serious and how big the difference is in behavior of different antennas when they become wet.

High Q factor of antenna can be the result of arbitrary chosen or reduced natural physical dimensions of antenna. Antennas with resonant passive elements like Yagi antennas, from which the last tenth of decibel of gain is squeezed, can also have very low radiation resistance and high Q factor. Illustration of such antenna is a Yagi antenna from authors to whom squeezing of highest possible antenna gain, was the main objective during antenna optimization.

The optimum antenna design has to find optimum compromise between few mutually confronted demands, from which all of them never can be satisfied simultaneously.

Antenna projecting is not an easy task if one wants to design really optimum antenna characteristics for specific application.

Analyze of water influence to antenna properties

During this analysis I investigate water influence to properties of following antennas: Bi-quad, 3D Corner Reflector Antenna, Amos Antenna and three Yagi antennas with different input resistances of 9, 12 and 50 ohms.

Results can be extrapolated to similar type of antennas which are derived from these antennas or use similar working principles. Some of them can be the combination of one antenna as a feed with passive parabolic reflector, for instance short Yagi antenna as a feed for parabolic reflector which are focusing Yagi antenna radiation.

Moisture on antenna elements is simulated so that on radius of bare copper wire coat of water, as increasing of overall wire radius, is added.

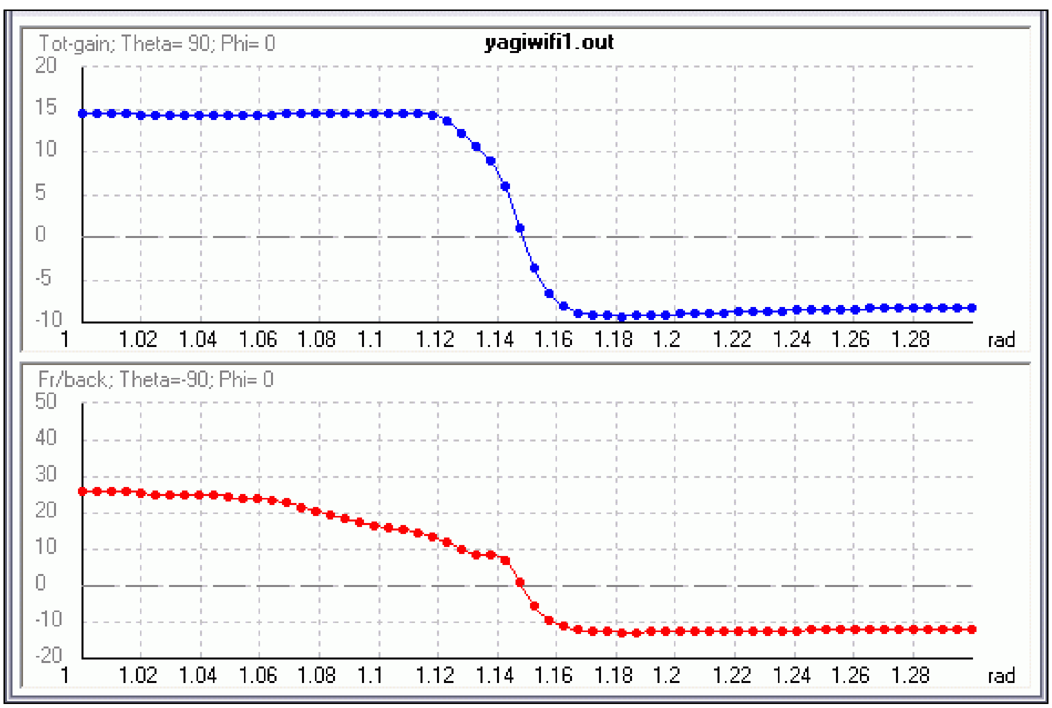
Wire radius of bare copper wire is normalized, and taken as 1 and then overall wire radius is increased by various water coat thickness to 1.1, 1.2 … etc.

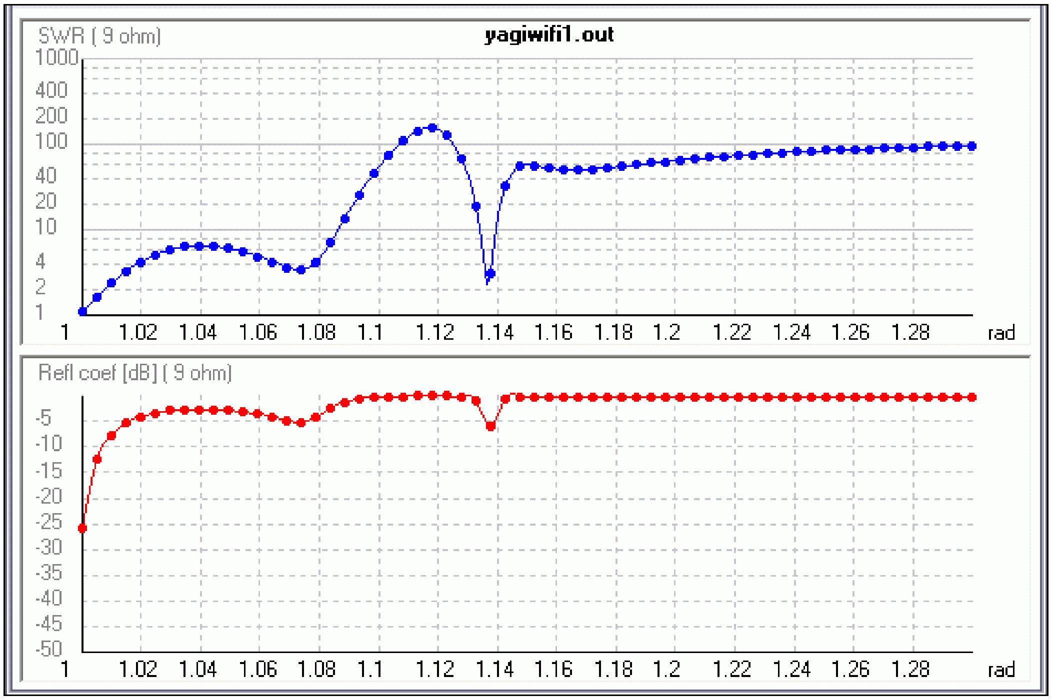
The antenna behavior is monitored using gain and input impedance that is SWR changing.

I assume that the water is very pure with very low conductivity, which is the best possible situation because in that case conductive RF loss is minimal. For dielectric permittivity I take value of Er=70, but it is important to say that results were almost same for all values above Er=10–15.

In this way only antenna de-tuning due to different equivalent dielectric permittivity, without any additional resistive loss, is considered.

If we know in practice, rain or condensing water is not so pure and they have pretty poor RF insulation properties. Thus, then in practice, we can expect additional losses which are not taken into account in this analysis. Accordingly, this is a better situation because in practice we have to expect even worse results due to increased resistive losses of ionized water.





Gain and SWR behavior of Yagi antenna with 9 ohms input resistance

Analysis results

Let's start from outsiders to favorites. The most prominent outsiders are Yagi antennas with very low input resistance, hence very low radiation resistance.

With increasing of Yagi antenna radiation resistance, results become better and antennas show less performance degradation due to moisture on elements.

For easier antenna comparison -3dB gain decreasing and SWR rising to 3 will be used as practical limits for acceptable antenna working.

Yagi antenna with 9 ohms input resistance

From the given diagrams it can be seen that when antenna elements become wet, due to rain, moist or condensate, and increase elements wire radius due to water coating to 1.15 or 15% the antenna stops working. Antenna gain decreased severely from +15 dBi to -4 dBi.

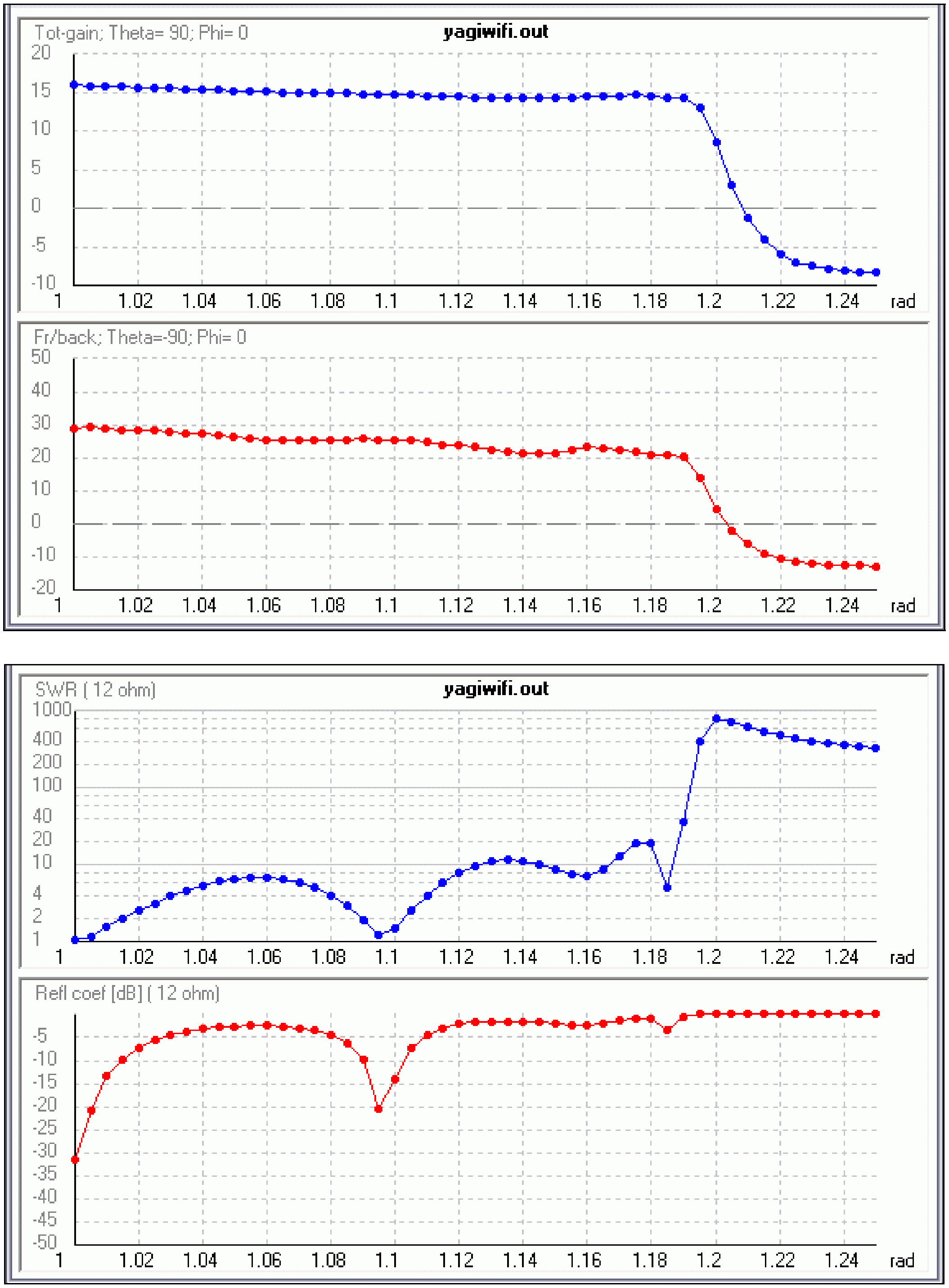
But even before that, SWR becomes problematic, because at antenna elements radius increase of only 1.5 % the SWR approaches a limit of 3.

It means that for Yagi antenna elements with radius of 1mm only 0.015 mm of moist is enough to completely ruin antenna performance.

With water layer which is 12% of element radius the antenna will still have around 15 dBi of gain but the SWR is over 150!

Yagi antenna with 12 ohms input resistance

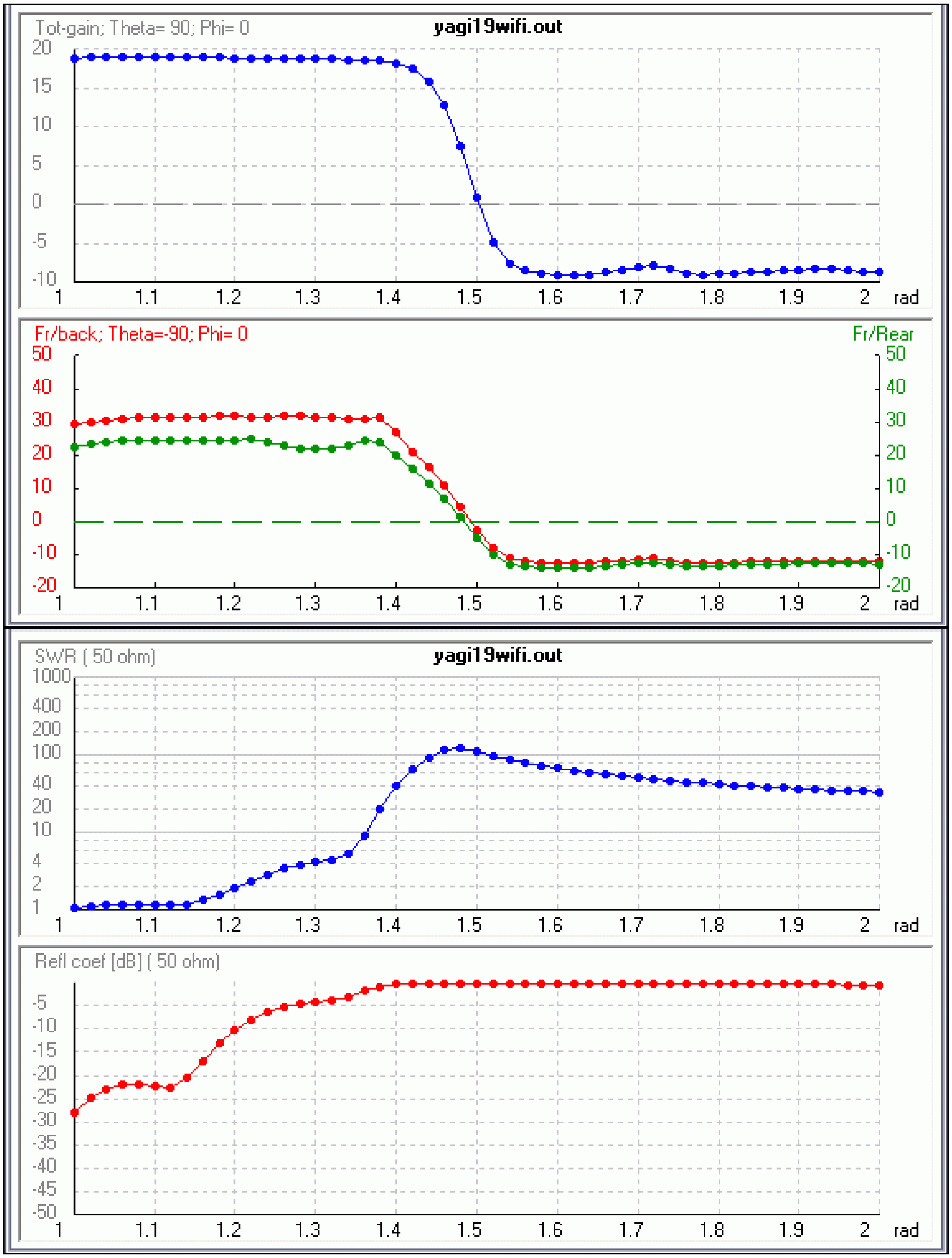
This antenna is only a little better than the previous one. Its gain falls rapidly at about 20% of water thickness compared to the element radius, but the SWR already becomes unacceptable at only 2 % of the antenna element radius.



Gain and SWR behavior of Yagi antenna with 12 ohms input resistance

Yagi antenna with 50 ohms input resistance

This is a Yagi antenna at which radiation resistance is not sacrificed in order to squeeze out the last tenths of dB of antenna gain. Results for this very good Yagi antenna are better than for the previous antennas, but still show that Yagi antennas are sensitive to moist weather. At about 40% of radius increase, the antenna still can work with good gain but SWR is about 40! Considering SWR antenna is usable only to about 25% of radius increase.



Gain and SWR behavior of Yagi antenna with 50 ohms input resistance

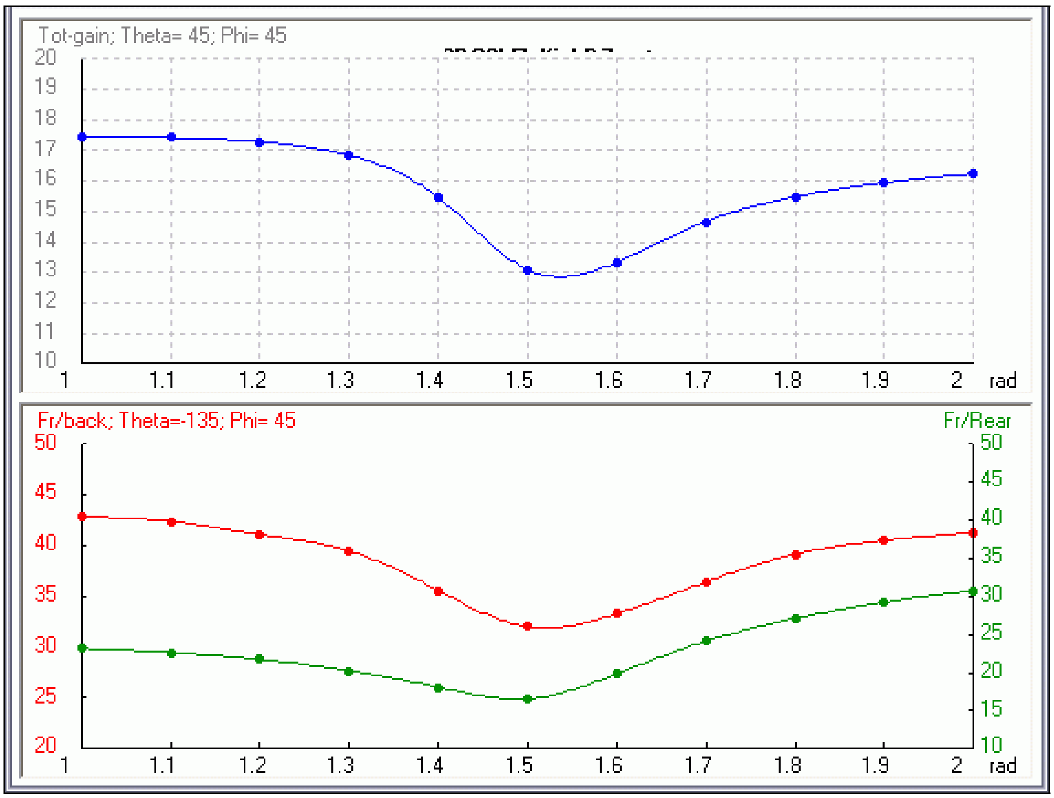
3D Corner Reflector antenna with 50 ohms input resistance

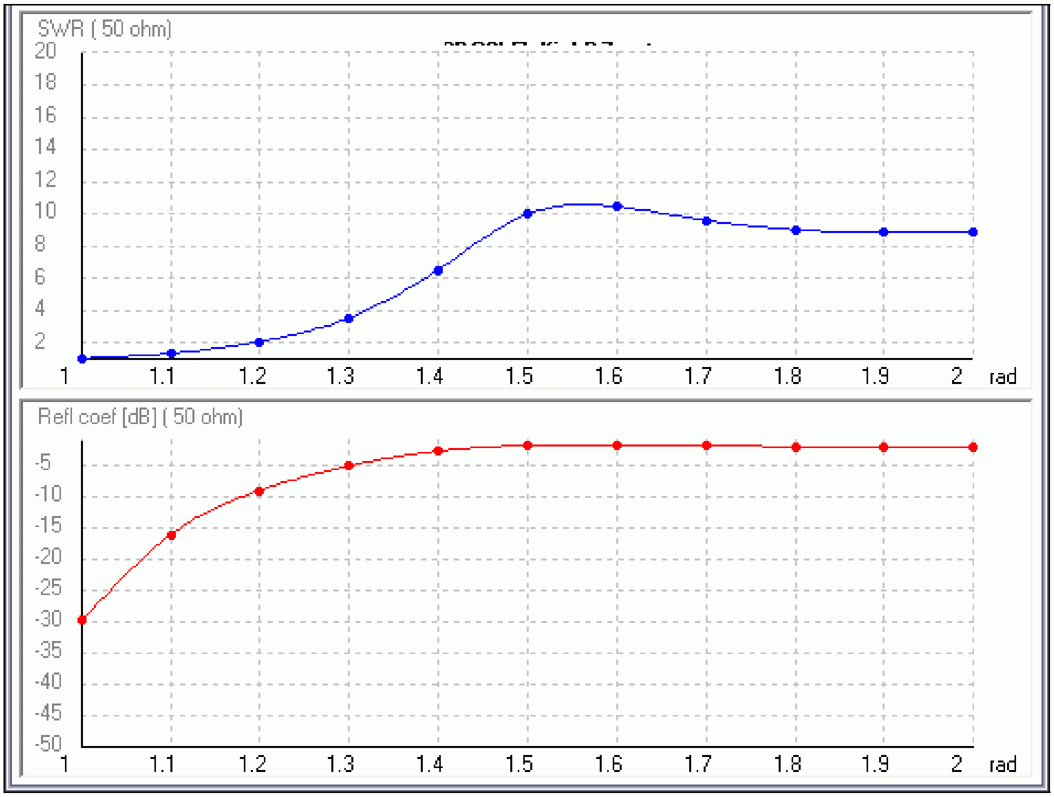
This antenna with its radiator and passive director element presents a similar antenna as the two element Yagi antenna with 3 D corner reflector.

A similar antenna is the classical corner reflector antenna with its open dipole radiator element in front of two planes corner reflector. Results are also similar for deep parabolic reflectors and 2-3 el Yagi antennas as feed.

In these results for the first time, we have relative good parallelism between gain decreasing and the SWR increasing with the increase of water skin on elements.

3D Corner Reflector antenna will work with acceptable SWR and gain up to 25% of the element radius increase.





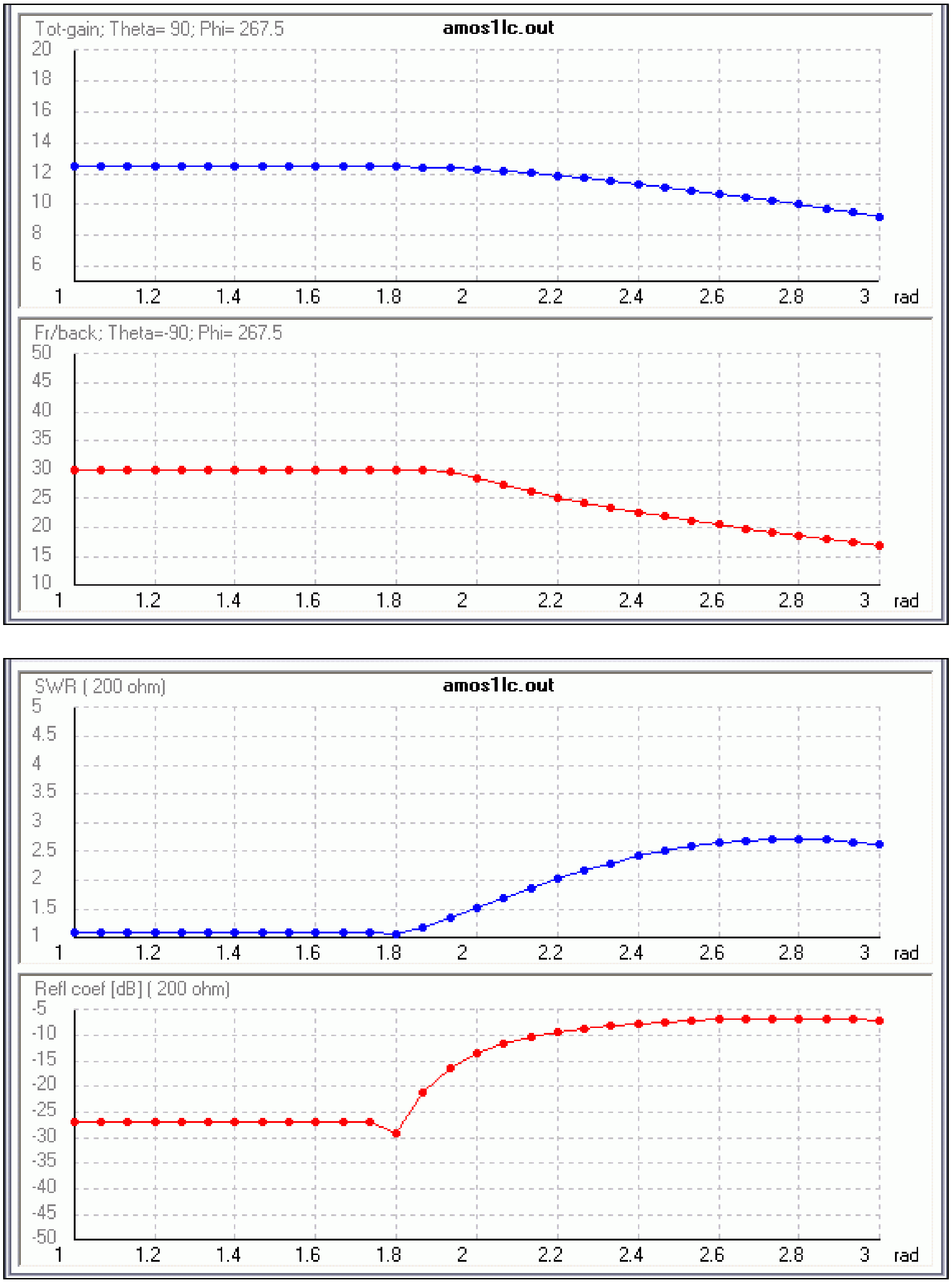
Gain and SWR behavior of 3D Corner Reflector antenna with 50 ohms input resistance

Amos collinear antenna with input resistance of 200 ohms

The Amos antenna is interesting for analysis at least for two reasons. The first one is the fact that the antenna consists of resonant half wave dipoles similar as the Yagi antenna, but only two of them are on one side opened, while all others are connected to nearby ones and don't have open ends so to the effect they behave analogous to closed loops.

The second reason is very high input resistance which is much higher than for all other analyzed antennas.

From the result, we see we have very good agreement between gain decrease and SWR increase.
It is interesting that SWR value for the worse case is less than 3, so that the gain decrease is only as acceptable limit for a wet Amos antenna. If we take -3 dB for gain decrease, then the Amos antenna can work with three times or 300% increase of the elements radius. Under those conditions it will have about 9.5 dBi and SWR of 2.6!

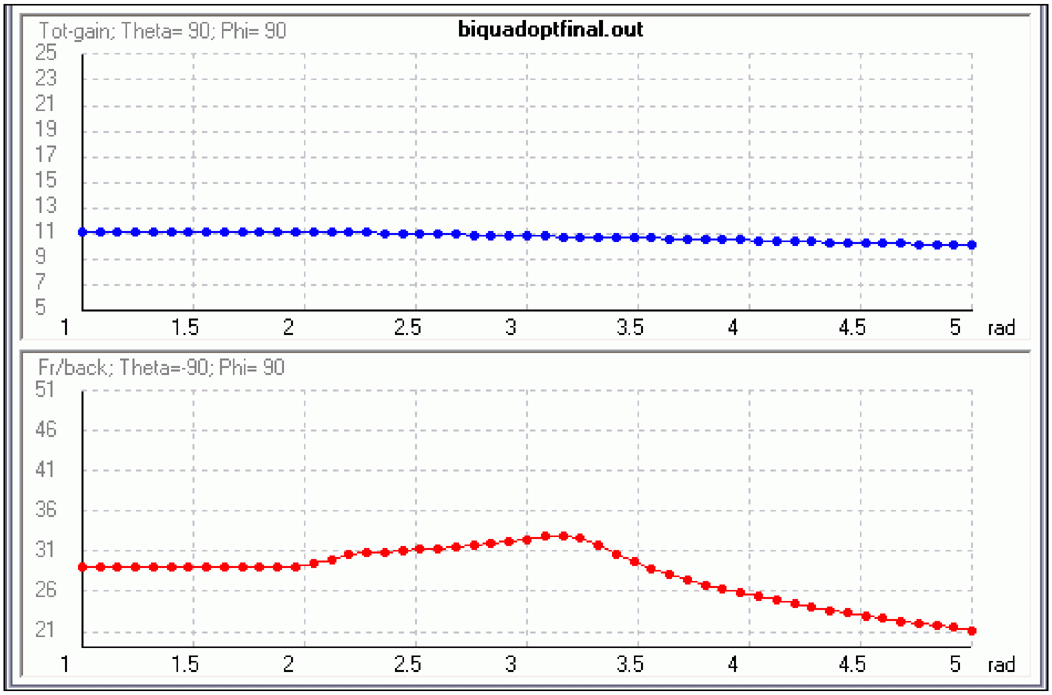


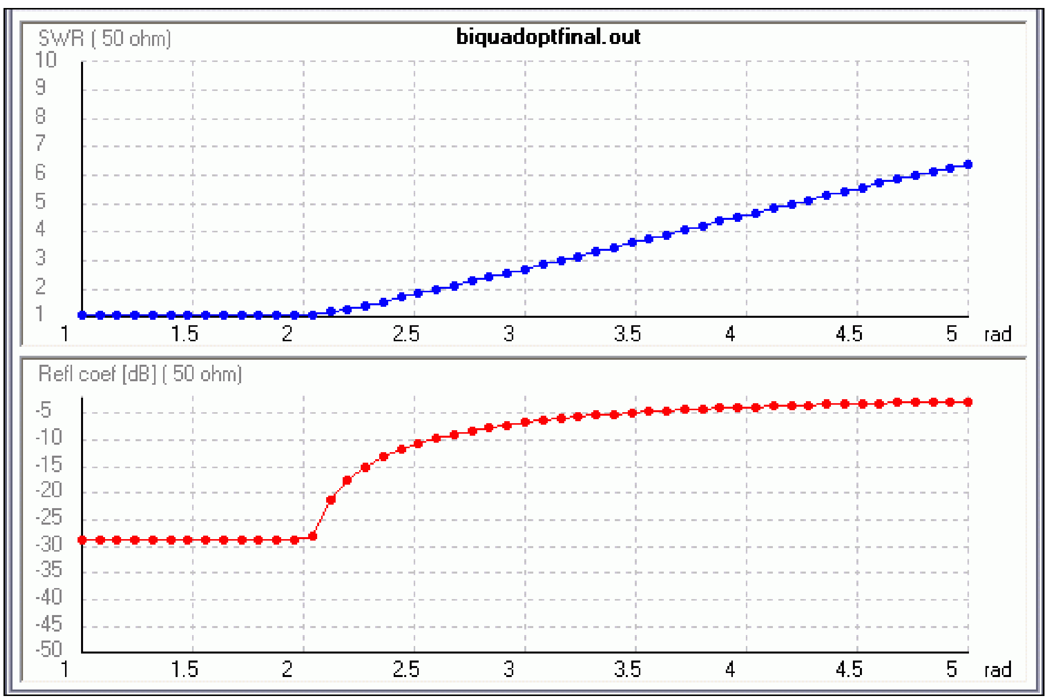
Gain and SWR behavior of Amos collinear antenna with 200 ohms input resistance

Optimal bi-quad antenna with input resistance of 50 ohms

In regard to immunity to moist conditions, the bi-quad antenna is far superior. It is due to its construction with radiator elements made as closed loops. Closed loops don't have open end tips and consequently they are less sensitive to dielectric permittivity change at points with high electric field as the element end tips are.

The bi-quad antenna can work up to a 320% increased element radius with almost unchanged gain and with SWR=3.



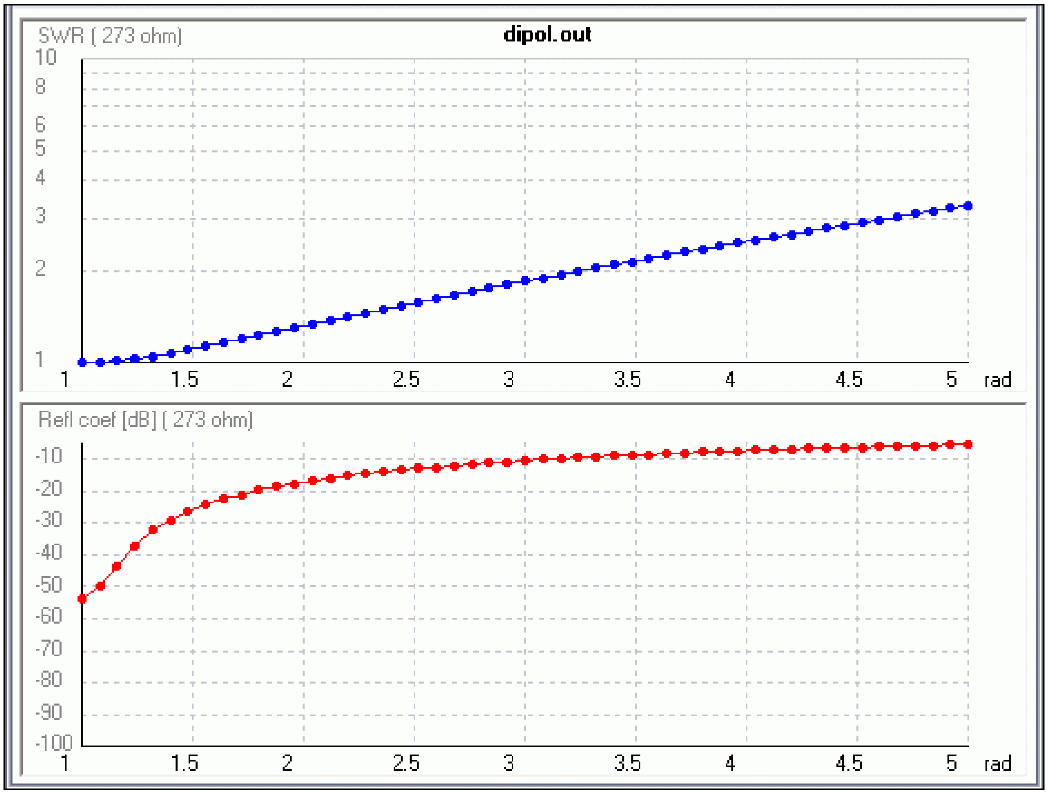


Gain and SWR behavior of bi-quad antenna with 50 ohms input resistance

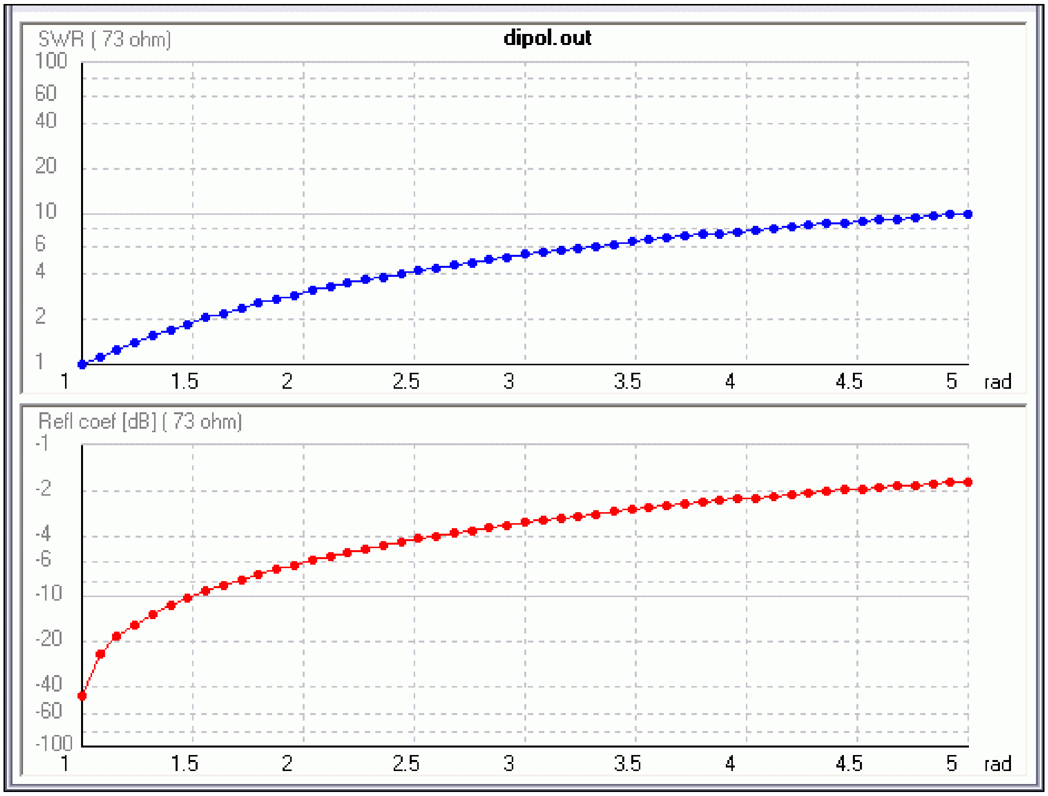
Open and folded dipole

The folded dipole behaves much better when it becomes wet than an open center-fed one which has the open end tips with high electric field. Every change of dielectric permittivity in this region can produce severe detuning of resonance.

This can be very easily seen from the results of analysis. The folded dipole reached SWR=3 at 450% of wire radius while the open center-fed dipole reached same SWR value at less than half of that value. For 200% of radius, the open center-fed dipole has an SWR=3.



SWR behavior of folded dipole antenna with 273 ohms input resistance



SWR behavior of open center fed dipole antenna with 73 ohms input resistance

Weather Protection

Antennas with small number of resonant elements sensitive to moisture can be protected from negative effects by placing them inside of some plastic box or tube. Unfortunately, the effects of plastic box or tube on antenna performance very often can also be negative, especially when the box also becomes wet due to rain or condensation.

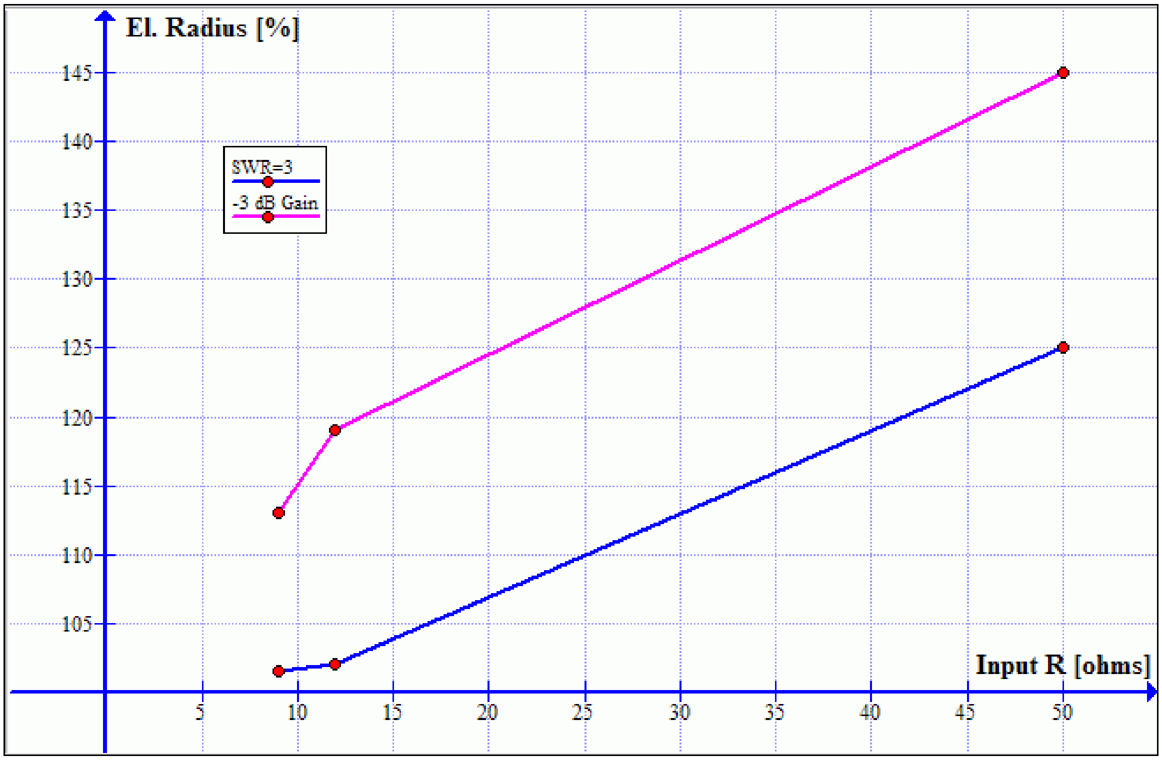
Yagi antennas are very problematic when protection is used by a plastic box or tube enclosure because they can change their performances due to the plastic cover's dielectric permittivity and RF losses.

Conclusion

This analysis of antennae performance in moist conditions is investigated with the aid of computer simulation.

Water with its extremely high dielectric permittivity presents a very remarkable factor of disturbance when it coats metal conductors. Because of this influence, the resonance of the antenna shifts to another frequency.

For resonant antennas with parasitic elements, which achieve its high gain and good input matching impedance due to precisely tuned currents magnitude and phase in elements, this disturbance can be fatal for antenna performance especially obvious for some particular antennas.



Radius of antenna elements with water coat for –3dB gain decrease and for increase of SWR to 3, depending on Yagi antenna input resistances

In this analysis, only high dielectric permittivity effects are considered.
But in practice, due to water impurity, wet antennas can have additional resistive losses.
Water layer on each element here is assumed as being uniform (which is unlikely in practice). Its thickness is given as an increase of normalized (bare) wire radius which is used as 1 or 100%. So the radius value which is greater than 1 is the overall radius of metal wire and the water coating. [1]
The analysis shows that antennas with higher input resistance (which very often means higher radiation resistance and lower Q factor of the antenna) is a very important consideration for how an antenna will behave in moist conditions.
On the other hand some constructions of antennas, such as closed-loop radiators, show better behavior under moist conditions. For instance, quad loops and folded dipoles are much more immune to the detuning effects of water.
Resonant closed loops of 1 wavelength circumference, independently of its shape (circular, square, or in a shape of other polygon), are less sensitive to water detuning effects than an open half-wave center-fed dipole.
It is found that the 2.4 GHz Yagi antennas are much more sensitive to SWR value change than on gain decrease due to the water coat on their elements. It is especially pronounced for antennas with very low input resistance (see diagram).
This antennas analysis and derived results are only illustration of a general trend of behavior of different antennas in moist weather conditions. They can't be used as absolutely accurate prediction of the antenna performances under those conditions due to

some approximations and known antenna program limitations in simulation of insulated wires [1].

Reference

1. Insulated Wires - The NEC-2 Way, L.B. Cebik, Antenna Modeling, http://www.antennex.com/library/w4rnl/col0105/amod83.html
2. 4nec2, NEC based antenna modeler and optimizer by Arie Voors, http://home.ict.nl/~arivoors/

BRIEF BIOGRAPHY OF THE AUTHOR

Dragoslav Dobričić, YU1AW, is a retired electronic engineer and worked for 40 years in Radio Television Belgrade on installing, maintaining and servicing radio and television transmitters, microwave links, TV and FM repeaters and antennas. At the end of his career, he mostly worked on various projects for power amplifiers, RF filters and multiplexers, communications systems and VHF and UHF antennas.

For over 40 years, Dragan has published articles with different original constructions of power amplifiers, low noise preamplifiers, antennas for HF, VHF, UHF and SHF bands. He has been a licensed Ham radio since 1964. Married and has two grown up children, a son and a daughter.

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